Fungal *Pleurotus species* as a Biosorbent for Heavy Metal Removal in Electroplating Wastewater

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

Manav Rachna International Institute of Research and Studies
(Deemed to be University)

by

Meena Kapahi
(Regn. No.: 10019990131)

Under the supervision of
Dr. Sarita Sachdeva
Professor, Biotechnology
Department of Biotechnology

FACULTY OF ENGINEERING AND TECHNOLOGY

MANAV RACHNA INTERNATIONAL INSTITUTE OF RESEARCH & STUDIES

SECTOR-43, SURAJKUND –DELHI ROAD, FARIDABAD – 121001

FACULTY OF ENGINEERING AND TECHNOLOGY

Certificate

I hereby declare that the short synopsis "**Fungal *Pleurotus* species as a Biosorbent for Heavy Metal Removal in Electroplating Wastewater"** being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Department of Biotechnology under Faculty of Engineering and Technology of Manav Rachna International Institute of Research & Studies, Faridabad, during the Academic Year 2010-2011.

It is a bona fide record of original work carried out under the supervision of Dr Sarita Sachdeva and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

Meena Kapahi
(Regn. No.: 10019990131)

Not Applicable

Signature of the Supervisor
Dr. Sarita Sachdeva
Professor Biotechnology, FET

Signature of the Joint-Supervisor
Full name, designation and faculty

Chairman, DRC

Chairperson

ABSTRACT

Time has over reached when it should be every one's concern to protect the environment in order to make Earth a beautiful and green place to live. Anthropogenic activities mainly have deteriorated the environment to an alarming level that it becomes the responsibility of everyone to save the environment from degradation. Since the problem of environment degradation is global, a concerted effort needs to be launched to inculcate environment-consciousness among all and to create it through different media, education, visual and performing arts to preserve the delicate balance in the entire ECOSYSTEMS, that has been disturbed, for destructive trend to be slowed down if not completely reversed. India has taken various initiatives to tackle the pollution problem incuding "The Pradhan Mantri Ujjwala Yojna Household LPG Programme", and "the National Clean Air Programme". Even Supreme court of India has taken a stringent view about use of fire crackers being the source of air pollution. The court has also been stringent about tackling water pollution by impressing upon Clean Ganga Mission. The mistakes we have made have caused animals and habitats to go extinct and for people to get sick. It is now vital for people of the world to embrace ENVIRONMENTAL CONCIOUSNESS. By making conscious decisions and taking appropriate actions, we not only make the planet a place for the present and the future generations. Even when achieving sustainability remains a key goal of development, precisely how this will happen can vary across places and functional machineries of government and its programmes. This study investigates the Green footprints, one measure to bring about sustainability, especially in developing countries. The discussion centers on role of technology in changing scenario of democratic political structure, old and obsolete treatment methods, weak implementations and state and central inequalities in policy and approaches and efforts are to understand the biosorption ability of mushroom and its derivatives as a new bioremediation approach.

"This Planet is our Legacy to the Future Generations, We Need to Sustain it"

Keywords: Environment, Technology development, Green footprints, Bioremediation

CONTENTS

S. No.	Description	Page No.
1	Introduction	5-9
2	Literature Review	9-11
3	Description of Broad Area	11-12
4	Objectives of the Study	12
5	Methodology to be Adopted	12-13
6	Expected Outcome of the Research	13
7	References (Harvard Style/APA/MLA)	14-18

1. INTRODUCTION

Water covers three-fourth of the Earth's surface; and that too, in the form of oceans (approximately 98%) and other fresh water bodies like lakes and rivers (0.036%), rest in aquifers and in polar ice caps and glaciers (U.S. Geological Survey 2000). Clean water is very critical for the existence of organisms and other life forms on this planet, its scarcity can affect health, food security and livelihoods of families across the world and wipe off entire Life forms from the face of the PLANET.

Major water bodies across the globe are suffering the plight of industrialization. Water pollution and deteriorating water quality are serious global issues arising due to increasing human population and the resulting so called developmental activities. Approximately, 25% of water pollution is caused by industries (Desai 2014). Hazardous substances discharged from the industrial activities is causing both surface water and ground water contamination (Haseena et al. 2017). Toxic metals from various industries enter in to water and reduce the quality of water. Contamination depends upon the nature of industries, process employed, the frequency of discharge and the use of heavy metals.

Heavy metal pollution is a matter of great concern because of their hazardous effects even at very low concentrations and their tendency for bioaccumulation in tissues. They can be discharged in the surroundings from a number of natural causes like weathering of geological bedrock. The type of heavy metals released from the rock substratum depends on its composition (Tchounwou et al. 2012; Wuana and Okieimen, 2011). The atmospheric deposition has also been reported to be one of the major causes in urban and sub-urban areas. Heavy metal contamination occurs directly from industries (tannery, electroplating, dyeing) and waste treatment plants. Various activities including coal mining and steel production are some of the causes of zinc. Electroplating units release heavy metal like chromium, cadmium, lead etc. percolating deep into the soil layers. Indirect heavy metal pollution results from contaminated surface or ground water and rain water (Vijayaraghavan and Yun 2008). The fate of the heavy metals and their effects further depend on the metal and its chemical form; and the age and nutritional status of the individual. Once a metal is absorbed, it gets distributed in body tissues and tends to persist in the body in organs like bones, liver and kidneys for a very long time.

Heavy metals like As, Cd, Hg and Pb are toxic (Brown and Absanullah 1971) and can lead to hazardous effects depending on their dose, exposure, one's gender, age and nutritional status. Heavy metals may produce tissue damage leading to a number of disorders.

- **Cadmium (Cd, Atomic No. 48)**

Cadmium, a carcinogenic metal, is present as a small component in sulfide ores of Zn. It is very toxic even in low concentrations and produces chronic effects on the environment. Naturally, Cadmium, is found in volcanic emissions, soil particles, forest fires, etc. Cadmium finds uses in various applications like anti-corrosive plating for steel, cadmium sulfide as pigments, and cadmium compounds in electric batteries and nuclear fission reactions. Its waste stream occurring through fossil fuels, zinc production, household waste burning and industries ends up in soils. Phosphate fertilizers are a main source of dispersed cadmium pollution. Deposition from atmosphere happens to increase the top soil cadmium concentration. It gets adsorbed by soil organic matter, which can enter in the food chain. Its availability to the soil biota is dependent on soil characteristics, presence of competing ions, etc. Acidified soils enhance the cadmium uptake by plants which gets accumulated in the plant eating animals. Soil biota like earthworms are very susceptible to cadmium even at very low concentrations.

In aquatic environment, cadmium enters through sediment erosion, waste water discharge, industrial effluents and atmospheric sources. Being water soluble, cadmium compounds are more mobile and hence bioavailable to the organisms. Its solubility in water is dependent on acidity; increase in acidity accelerates the dissolution of cadmium. Under natural conditions, cadmium is found in suspended particles and sediments at the bottom. In marine ecosystems, cadmium concentration may increase in aquatic animals; cadmium bio accumulates in oysters, lobsters, fish, etc. Prolonged cadmium exposure leads to its accumulation in the body, bone demineralization, impair kidney and lung function. Low exposure to cadmium leads to adverse impacts on kidney and bones and lung cancer and prostate cancer (Bernard 2008).

- **Lead (Pb, Atomic No. 82)**

Lead, though found in small amounts in the earth's crust naturally, has been contributed in high concentrations by man-made activities like mining and smelting operations, fossil fuels burning,

building materials, lead storage batteries, pigments and dyes, etc. Exposure to lead via ingestion/inhalation while eating/breathing (Ferner 2001) can lead to health problems like impaired haemoglobin synthesis and kidney functions, damage to reproductive systems, central nervous and circulatory systems (Ogwuegbu and Muhanga 2005). It can result in permanent brain damage. Dust, leaded paints can often lead to its increased concentrations in blood especially children affecting brain development (Udedi 2003).

- **Heavy metal removal**

Conventional methods like chemical precipitation, adsorption, ion exchange, reverse osmosis and electro-dialysis, to get rid of heavy metal burden of the environment, have their own shortcomings. The process of chemical precipitation is used to remove heavy metal removal from by adding anions for precipitating metals as suspended particles, which are then removed. The process is not specific in nature and cannot remove heavy metal at low concentrations. Through Ion exchange process, heavy metals to the level of ppb can be removed (Hassan et al. 2010). But, the process is non-specific, pH sensitive and is an expensive method. The methods like reverse osmosis and electro-dialysis make use of membranes. The conventional methods offer limitations like slow metal precipitation and incomplete removal (Aziz et al. 2015), generation of contaminated sludge requiring careful disposal (Gunatilake 2015; Ayangbenro 2017), high cost involved in the processes (Firdousi 2017), high energy and reagent requirements and clogging of membranes.

It becomes important to choose an economical remediation technique which is effective and does not have these disadvantages. Bioremediation is a way of cleaning up heavy metals using biomass (or microorganisms) through the processes of biodegradation, biosorption, bioaccumulation and bioconversion operating in different ways (Kulshreshtha et al. 2014; Mosa et al. 2016). The microorganisms bind to heavy metals and concentrate them (Joutey et al. 2015) through biosorption. Biosorption works as a passive process and heavy metals get adsorbed on the surface of the biosorbent (Velásquez and Dussan 2009) exhibiting the tolerance of biosorbent towards heavy metals. Different microbial agents (like algae, bacteria, fungi) are reported to carry out biosorption.

- **Mycroremediation**

Mycoremediation is the form of bioremediation that employs fungi to remove environmental contaminants. Fungi are the most vital agents for the nutrient cycling. Fungi have adapted (in terms of their morphology, ecology and metabolism) according to environmental conditions and are present everywhere in environment. Under natural conditions, fungi are responsible for processes like decomposition and nutrient cycling. They have been reported to withstand and survive under stress conditions of moisture, nutrients, pH etc. Mycoremediation involves fungus for the removal of contaminants from different environmental segments/substrates (Hamba & Tamiru, 2016). Mycoremediation, a cost-effective process, does not leave harmful waste products. Hence, it poses a complete solution because of full mineralization of the pollutants in nature (Thenmozhi et al., 2013). Its success depends on the identification and usage of a suitable fungal species for the target heavy metal or other contaminants. Fungi remove pollutants like heavy metals in an efficient manner by accumulating them in to the fruit bodies (Ogbo and Okhuoya, 2011). *Saccharomyces cerevisiae* has been reported to remove Pb and Cd from polluted soil up to 65–79% (Damodaran et al. 2011). Fungi can remove heavy metals in both living and dead forms in two ways: passive process constitute binding of heavy metal ions to the cell walls and does not involve metabolism; and active uptake or bioaccumulation involves uptake by the cells (intracellular uptake). The process of biosorption involves fungal cell walls (having chitin, proteins, glucans, lipids, pigments, polysachharides) and functional groups like hydroxyl, carboxyl, amino, sulfate or phosphate and is mediated through interactions like adsorption, ion-exchange and complexation (Ismail and Moustafa, 2016).

Mushrooms have been relished as food since a long-time due to their nutritional and medicinal properties. Mushrooms are rich in proteins and fibres and lack cholesterol. Mushroom cultivation converts agro- and ligno-cellulosic wastes in to a protein rich food. Besides their use a food, mushrooms are used for the mycroremediation of heavy metals; and hence, should be avoided. Mushrooms being a food crop and looking at the potential of mushroom mycelia, the spent mushroom substrate (SMS) produced after harvesting the mushroom can be used for the mycoremediation of the degraded sites. The aged mycelia, SMS, are otherwise generated in huge amounts by the mushroom farms and pose a disposal problem. Mushrooms absorb heavy metals in their mycelium with the help of biosorption process; Mushrooms employ various mechanisms including biodegradation, biosorption and bioconversion to remediate the polluted environment.

- **Advantages of mycoremediation**

Fungi can efficiently remove heavy metals from contaminated media because of the presence of materials enabling excellent metal-binding. The fungal cell walls provide sites for cation exchange due to the presence of negative charges (Fomina et al. 2007). Apart from that, using waste fungal biomass for bioremediation owing to their availability and economical production can go a long way to be an effective method to clean heavy metal contamination.

2. LITERATURE REVIEW

Fungal biomass is used for biosorption of heavy metals removal from polluted waters because of its excellent metal sorption properties and excellent tolerance in the adverse environment (Salman et al. 2014). Fungi can chemically alter their availability for organisms. Fungi have chitin in their walls which can bear metals and low pH and temperature conditions. The mechanisms like extracellular and intracellular sequestration of heavy metals are responsible for heavy metals tolerance in fungi.

Mushrooms, macro-fungi, have fruiting bodies that grow out of a mass of mycelium. They are a favourite delicacy in many parts of the world. Biosorbent from mushrooms can be prepared from mycelium or fruit body (live or dead) and spent mushroom substrate (SMS). Mushrooms have also been reported as nutraceuticals having anti-oxidant, anti-cancer, immunostimulatory and anti-inflammatory therapeutic features (Barros et al. 2007; Kim et al. 2007; Sarikurkcu et al. 2008; Synytsya et al. 2009) because of their chemical composition. Apart from this, mushrooms can be employed for decontamination of the polluted environment. Mushrooms can build up heavy metals in great amounts in their bodies above maximum permissible concentrations (Kalac and Svoboda 2000) and can act as an effective biosorption tool (Das 2005). High accumulation potential and shorter life span are some of the advantages of using mushrooms as biosorbents. Different species can degrade persistent pollutants including *Pleurotus ostreatus, Trametes versicolor, Lentinula edodes, Agaricus bisporus* (Table 1).

- ***Pleurotus* species**

The genus *Pleurotus*, commonly called Oyster mushroom, is a type of gilled mushrooms which grows normally on wood. It encompasses many species, for example *P. ostreatus, P. pulmonary, P. sajor-caju, P. cornucopiae, P. sapidus, P. platypus* and *P. ostreatoroseus*. It is found all around the world, mainly in forest environments. The genus has enzymes like laccase and Mn-peroxidase which enable them to utilize different types of agro-wastes with broad adaptability to varied agro-climatic conditions (Agrahar-Murugkar and Subbuakshmi 2005). A number of substrates like wheat straw, corn and sawdust can be used for its cultivation. They are popular and are widely cultivated throughout the world for food owing to simple production technology and their higher biological efficiency (Manzi et al. 2001). The mushroom is rich in vitamins, proteins, fibres, carbohydrates and minerals and owns a very pleasant taste. It is rich in immense therapeutic properties (Kalac and Svoboda 2000). There has been a rise in research activities related to the genus because of its multiple uses including biosorption.

Fungal species	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**	**Ref**
Agaricus bisporus, Pleurotus ostreatus			X		X					X		Frutos et al. 2016
Agaricus bisporus		X	X	X						X		Al-Hares 2017
Alternaria alternate, P. aurantiogriseum		X					X					Bahobil et al. 2017
Aspergillus sp.									X			Amini et al. 2009
A. flavus, A. fumigatus, Paecilomyces sp., Clad osporium sp., Mucor sp.	X											Cårdenas-Gonzåles 2017
A. flavus, A. gracilis, A. penicillioides, A. restrictus, Sterigmatomyces halophilus		X			X	X		X		X	X	Bano et al. 2018
Aspergillus, Rhizopus sp.		X	X									Ahmad at al. 2005
Aspergillus sp., *Penicillium* sp.		X										Manguilimotan et al. 2018

Schizophyllum commune			X		X				X		X	Javaid and Bajwa 2008
P. ostreatus			X		X	X					X	Arbanah et al. 2012
P. ferulae										X		Adebayo 2013
P. ostreatus										X		Jiang et al. 2017
P. florida Trichoderma viride										X		Prasad et al. 2013
Rhizopus nigricans										X		Kogez et al. 2010
R. arrhizus			X									Shoaib et al. 2013
Penicillium coffeae	X											Bhargavi and Savitha 2014
A. flavus, A. fumigatus, Mucor sp.							X					Mart´ınez-Ju´arez et al. 2012
Penicillium janthinillum	X											Mamisahebei et al. 2012
Termitomyces clypeatus			X									Ramrakhiani et al. 2011

Table 1. Bioremediation by fungal species of different Heavy Metals

3. DESCRIPTION OF BROAD AREA

Pleurotus species have high biosorption capacity for heavy metals (Table 1). The accumulation of heavy metals in the fruit bodies tends to increase with an increase of the metals in the substrate (Ogbo and Okhuoya 2011). Heavy metals are majorly found in polluted sites like highways and cement- and battery-waste polluted sites. Oyster mushrooms in the contaminated areas can accumulate heavy metals. As reported by Barcan et al. (1998), "mushrooms (near the smelters) can concentrate nearly 1540 times more than the background level of nickel". The bioaccumulation potential of *P. ostreatus* from metal scrap sites has also been evaluated for Cu, Fe, Zn and Mn (Boamponsem et al. 2013). However, the accumulation potential of the species varies with the metallic species. Differences in accumulation potential for different heavy metals may be ascribed to the various types of growth substrates found in ecosystems. In a study conducted by Brunnert and Zadraz □il (1983), more Hg than Cd has been found to be accumulated in fruiting bodies in *P. ostreatus*, while more Cd has been found in *P. flabellatus*. Purkayastha et al. (1994) reported

highest uptake of Cu and Cd as compared to Co and acid Hg ions by *P. sajor-caju*. However, the uptake of Cd was reduced in the presence of Cu in *P. sajor-caju* owing to the chemical interference. With these facts in mind, in the present study efforts will be made to understand the biosorption capacity of mushroom and the spent mushroom material for remediation purpose of Heavy Metals.

4. OBJECTIVES OF THE STUDY

For the present study, keeping in mind the literature survey, the following research objectives are designed:

- To study the characteristics of water from Electroplating Industries.
- To study the heavy metal profile of water from Electroplating Industries
- To optimise the cultivation of *Pleurotus* species
- To study the mechanism of heavy metal accumulation
- To study the biosorption potential of Cadmium and Lead by *Pleurotus* species
- To study the biosorption potential of heavy metals by SMS
- To conduct desorption studies in case of *Pleurotus* and its spent mass

5. METHODOLOGY TO BE ADOPTED

5.1 Estimation of Characteristics of Water from Electroplating Industries

The various physical, chemical and biological parameters from Electroplating Industries will be studied. The standard methods will be followed as per APHA guidelines (1985).

5.2 Estimation of heavy metals in water from Electroplating Industries

The profile of heavy metals in water from Electroplating Industries will be studied. The standard method for sampling as well as estimation will be followed as per APHA guidelines (1985).

5.3 To optimise the cultivation of *Pleurotus* species

The cultivation of *Pleurotus* species will be studied and then optimized to obtain maximum fruiting bodies and the quality spent mushrooms by focusing on the various parameters that effect the growth.

5.4 To elucidate the mechanism of heavy metal accumulation.

The accumulation mechanism of Heavy Metals by the fungi *Pleurotus* will be understood by TEM and SEM studies of the fruiting bodies and the SMS.

5.5 To study the biosorption potential of Cadmium and Lead by *Pleurotus* species

To study the biosorption capacity of *Pleurotus* sp. for Cadmium and Lead, the effects of the following parameters will be considered:

a. Particle size
a. pH
b. Temperature
c. Contact Time
d. Initial Concentration of Heavy Metals
b. Biomass Concentration

5.6 To study the biosorption potential of heavy metals by *Pleurotus* species SMS

To study the biosorption capacity of *Pleurotus* sp. SMS for heavy metals, the effects of the following parameters will be considered:

c. Particle size
e. pH
f. Temperature
g. Contact Time
h. Initial Concentration of Heavy Metals
d. Biomass Concentration

5.7. Desorption studies

The desorption studies will be conducted subject to availability of facilities and time frame.

6. EXPECTED OUTCOME OF THE RESEARCH

Heavy metals contamination is a major environmental concern these days. Heavy metals are highly toxic and display high mobility in aquatic systems (Rincon et al. 2005). Bioremediation techniques make use of biological materials/microorganisms like bacteria, algae or fungi. Fungi can bioremediate contaminated environment and reduce heavy metals from ppm to ppb level (Wang and Chen 2009). Fungi have adapted (in terms of their morphology, ecology and metabolism) according to environmental conditions and are present everywhere in environment. Under natural conditions, fungi are responsible for processes like decomposition and nutrient cycling (Archana and Jaitly 2015). They have been reported to withstand and survive under stress conditions of moisture,

nutrients, pH etc. *Pleurotus* species (oyster mushroom) comprise edible fungus used in Asian cuisine. Although different potential fungal biosorbents have been investigated, very little is known of the ability of *Pleurotus* species in heavy metals bioremediation. If the results show good capacity of holding the heavy metals, then *Pleurotus* species biosorbent is in-line with the alternative sustainable technology development for wastewater purification system.

7. **REFERENCES**

Abbas, H. S., Ismail, M. I., Mostafa, M. T., & Sulaymon, H. A. (2014). Biosorption of heavy metals: A review. *Journal of Chemical Science and Technology*, 3:74-102.

Adebayo, A. O. (2013). Investigation on *Pleurotus ferulae* potential for the sorption of Pb(II) from aqueous solution. *Bull Chem Soc Ethiop*, 27:25-34.

Agrahar-Murugkar, D., Subbuakshmi, G. (2005). Nutritional value of edible wild mushrooms collected from the Khasi hills of Meghalaya. *Food Chem*, 89:599-603.

Ahmad, I., Zafar, S., & Ahmad, F. (2005). Heavy metal biosorption potential of Aspergillus and *Rhizopus* sp. isolated from wastewater treated soil. *J Appl Sci Environ Mgt*, 2005;123-126.

Al-Hares, H. S. (2017). Single and binary biosorption isotherms of different heavy metal ions using fungal waste biomass. *Al-Nahrain J Eng Sci (NJES)*, 20(3):673-684.

Amini, M., Younesi, H., & Bahramifar, N. (2009). Biosorption of nickel(II) from aqueous solution by *Aspergillus niger*: Response surface methodology and isotherm study. *Chemosphere*, 75(11):1483-1491.

Arbanah, M., Miradatul, N. M. R., Ku Halim, K. H. (2918). Biosorption of Cr(III), Fe(II), Cu(II), Zn(II) ions from liquid laboratory chemical waste by *Pleurotus ostreatus*. *Int J Biotechnol Wellness* Ind., 1:152-62.

Archana, A., & Jaitlty, A. K. (2015). Mycoremediation: utilization of fungi for reclamation of heavy metals as their optimum remediation conditions. *Biolife*, 3(1):77-106.

Ayangbenro, B. (2017). A new strategy for heavy metal polluted environments: a review of microbial biosorbents. *Int J Environ Res Public Health*, 14:94.

Aziz, H.A., Adlan, M.N., & Ariffin, K.S. (2015). Heavy metals (Cd, Pb, Zn, Ni, Cu and Cr (III)) removal from water in Malaysia: post treatment by high quality limestone. *Bioresource Technology*, 99(6):1578-1583.

Bahobil, A., Bayoumi, R. A., Atta, H. M., & El-Sehrawey, M. M. (2017). Fungal biosorption for cadmium and mercury heavy metal ions isolated from some polluted localities in KSA. *Int J Curr Microbiol App Sci*. 2017;6(6):2138-2154.

Bano, A., Hussain, J., Akbar, A., Mehmood, K., Anwar, M., Hasni, M. S., Ullah, S., & Sajid, S. Ali. (2018). Biosorption of heavy metals by obligate halophilic fungi. *Chemosphere*, 199:218-222.

Barcan, V. S., Kovnatsky, E. F., & Smetannikova, M. S. (1998). Absorption of heavy metals in wild berries and edible mushrooms in an area affected by smelter emissions. *Water Air Soil Pollut*, 103:173-195.

Bhargavi, S. D., Savitha, J. (2014). Arsenate resistant *Penicillium coffeae*: A potential fungus for soil bioremediation. *Bull Environ Contam Toxicol*, 92:369-373.

Bernard, A. (2008). Cadmium & its adverse effects on human health. *Indian J Med Res*, 128(4), 557-64.

Boamponsem, G. A., Obeng, A. K., Osei-Kwateng, M., & Badu, A. O. (2013). Accumulation of heavy metals by *Pleurotus ostreatus* from soils of metal scrap sites. *Int J Curr Res Rev* 5(4):01-09.

Brown, B., & Ahsnullah, M. (1971). Effect of heavy metals on mortality and growth. *Mar Pol Bull*, 2:182-185.

Brunnert, H., & Zadraz □il, F. (1983). The translocation of mercury and cadmium into the fruiting bodies of six higher fungi. A comparative study on species specificity in five lignocellulolytic fungi and the cultivated mushroom *Agaricus bosporus*. *Eur J Appl Micorbiol Biotechno*l, 17:358-364.

Cárdenas-González, J. F., Acosta-Rodríguez, I., Téran-Figueroa, Y., & Rodríguez-Pérez, A. S. (2017). Bioremoval of arsenic (V) from aqueous solutions by chemically modified fungal biomass. *3 Biotech*, 7(3):226.

Damodaran, D., Suresh, G., & Mohan, R. (2011). Bioremediation of soil by removing heavy metals using *Saccharomyces cerevisiae*. In: 2nd international conference on environmental Science and Technology, IPCBEE, vol. 6.

Das, N. (2005). Heavy metals biosorption by mushrooms. *Indian J Natl Prod Resour*, 4:454-459.

Ferner, D. J. (2001). Toxicity, heavy metals. *Med J*, 2:1.

Firdousi, S.A. (2017). Bioaccumulation and bio-absorptions of heavy metals by the mushroom from the soil. J Med Chem Drug Discov, 2(3):25-33.

Frutos, I., García-Delgado, C., Gárate, A., & Eymar, E. (2016). Biosorption of heavy metals by organic carbon from spent mushroom substrates and their raw materials. *Int J Environ Sci Technol*, 2016;13(11):2713-2720.

Fomina, M., Charnock, J., Bowen, A. D., & Gadd, G. M. (2007). X-ray absorption spectroscopy (XAS) of toxic metal mineral transformations by fungi. *Environ Microbiol*, 9:308-321.

Gunatilake, S.K. (2015). Methods of removing heavy metals from industrial wastewater. *J Multidiscip Eng Sci Stud*, 1(1):12-18.

Hamba, Y., & Tamiru, M. (2016). Mycroremediation of heavy Metals and Hydrocarbons contaminated environment. *Asian Journal of Natural & Applied Sciences*, 5(2):48-58.

Haybron, D. M. (2008). Philosophy and the science of subjective well-being. In M. Eid & R. J. Larsen (Eds.), *The science of subjective well-being* (pp. 17-43). New York, NY: Guilford Press.

Ismail, I., & Moustafa, T. (2016). Journal of Chemical Science and Technology Oct. 2014, Vol. 3 Iss. 4, PP. 74-102 Biosorption of Heavy Metals. In D. Pathania (Ed.), Heavy Metals: Sources, Toxicity and Remediation Techniques. Nova Science Publishers

Kalac, P., & Svoboda, L. (2000). A review of trace element concentrations in edible mushrooms. *Food Chem*, 69:273-281.

Kim, H. Y., Yoon, D. H., Lee, W. H., Han, S. K., Shrestha, B., Kim, C. H., Lim, M. H., Chang W., Lim, S., Choi, S., Song, W. O., Sung, J. M., Hwang, K. C., & Kim, T. W. (2007). *Phellinus linteus* inhibits inflammatory mediators by suppressing redox-based NF-jB and MAPKs activation in lipopolysaccharide-induced RAW 264.7 macrophage. *J Ethnopharmacol* 114:307-315.

Kulshreshtha, S., Mathur, N., & Bhatnagar, P. (2014). Mushroom as a product and their role in mycoremediation. *AMB Express*, 4:29. doi:10.1186/s13568-014-0029-8

Hassan, S., Awad, Y.M., Kabir, M.H., Sang-Eun, Oh., & Joo, J.H. (2010). Bacterial Biosorption of heavy metals, January 2010. In book: Biotechnology Cracking New Pastures, Chapter Four. MD Publications Pvt Ltd., New Delhi

Haseena, M., Malik, M. F., Javed, A., Arshad, S., Asif, N., Zulfiqar, S., & Hanif, J. (2017). Water pollution and human health. *Environmental Risk Assessment and Remediation*, 1(3). http://www.alliedacademies.org/articles/water-pollution-and-human-health-7925.html. Accessed on 8/4/19.

Javaid, A., & Bajwa, R. (2008). Biosorption of electroplating heavy metals by some basiodiomycetes. *Mycopathologia*, 6:1-6.

Jiang, Y., Has, R., & Yang, S. (2017). Natural bioaccumulation of heavy metals onto common edible macrofungi and equilibrium and kinetic studies on biosorption of Pb(II) to them. Acta

Nat Univ Pekin,53(1):125-34.

Kogej, A., Bla` Likozar, B., & Pavko, A. (2010). Mathematical model of lead biosorption by *R.nigricans*. *Food Technol Biotechnol*, 48(3):344-351.

Manzi, P., Aguzzi, A., & Pizzoferrato, L. (2001). Nutritional value of mushrooms widely consumed in Italy. *Food Chem*, 73:321-325.

Manguilimotan, L. C., & Bitacura, J. G. (2018). Biosorption of cadmium by filamentous fungi isolated from coastal water and sediments. *J Toxicol*. Article ID 7170510, p.6. https://doi.org/10.1155/2018/7170510.

Mosa, K. A., Saadoun, I., Kumar, K., Helmy, M., & Dhankher, O. P. (2016). Potential biotechnological strategies for the cleanup of heavy metals and metalloids. *Front Plant Sci*,7:1-14. doi:10.3389/fpls.2016.00303.

Mart´ınez-Ju´arez V. M., C´ardenas-Gonz´alez, J. F., & Torre-Bouscoulet, M. E. (2012). Acosta-Rodr´ıguez. Biosorption of mercury (II) from aqueous solutions onto fungal biomass. *Bioinorg Chem Appl*, Sep 18;1-5. https://doi.org/10.1155/2012/156190.

Prasad, A. S. A., Varatharaju, G., Anushri, C., & Dhivyasree, S. (2013). Biosorption of lead by *Pleurotus florida* and *Trichoderma viride*. *Br Biotechnol J*, 3(1):66-78.

Purkayastha, R. P., Mitra A.K., & Bhattacharyya, B. (1994). Uptake and toxicological effects of some heavy metals on *Pleurotus sajor-caju* (Fr.) Singer. *Ecotoxicol Environ Safe*, 27:7-13.

Ogbo, E.M., & Okhuoya, J.A. (2011). Bio-absorption of some heavy metals by *Pleurotus tuber-regium* Fr. Singer (an edible mushroom) from crude oil polluted soils amended with fertilizers and cellulosic wastes. *Int J Soil Sci*, 6:34-48.

Ogwuegbu, M. O. C., & Muhanga, W. (2005). Investigation of lead concentration in the blood of people in the Copperbelt Province of Zambia. *J Env*, 1,66-75.

Raymond A. Wuana, A. R., & Okieimen, F.E. (2011). Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *ISRN Ecology*, 2011. Doi: https://doi.org/10.5402/2011/402647.

Rincon, J., Gonzalez, F., Ballester, A., Blazquez, M. L., & Munoz, J. A. (2005). Biosorption of heavy metals by chemically-activated alga *Fucus vesiculosus*. *J Chem Technol Biotechnol*, 80:1403-1407.

Salman, H.A., Ibrahim, M.I., Tarek, M.M., & Abbas, H.S. (2014). Biosorption of heavy metals—a review. *J Chem Sci Technol*, 3(4):74-102.

Sarikurkcu, C., Tepe, B., & Yamac, M. (2008). Evaluation of the antioxidant activity of four edible mushrooms from the Central Anatolia, Eskisehir—Turkey: *Lactarius deterrimus, Suillus collitinus, Boletus edulis, Xerocomus chrysenteron*. *Bioresour Technol*, 99:6651-6655. doi:10.1016/j.biortech.2007.11.062

Shoaib, A., Aslam, N., Makshoof A. M., Akhtar, S., Nafisa., K. S. (2013). Removal of Cr(III) through bread mold fungus. *Pol J Environ Stud*, 22(4):1171-1176.

Synytsya, A., Mickova, K., Synytsya, A., Jablonsky, I., Spevacek, J., & Erban, V. (2009). Glucans from fruit bodies of cultivated mushrooms *Pleurotus ostreatus* and *Pleurotus eryngii*: structure and potential prebiotic activity. *Carbohydr Polym*, 76:548-556. doi:10.1016/j.carbpol.2008.11.02

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *EXS*, 101, 133-64.

Thenmozhi, R., Arumugam, K., Nagasathya, A.,Thajuddin, N., & Paneerselvam, A. (2013). Studies on Mycoremedation of used engine oil contaminated soil samples. *Advances in Applied Sciences and Research*, 4 (2):110-118.

Udedi, S.S. (2003). From Guinea worm scourge to metal toxicity in Ebonyi State, Chemistry in Nigeria as the New Millennium Unfolds, 2(2),13-14.

Velásquez, L., & Dussan, J. (2009). Biosorption and bioaccumulation of heavy metals on dead and living biomass of *Bacillus sphaericus*. *J Hazard Mater*, 167:713-716. doi:10.1016/j.jhazmat.2009.01.044

Vijayaraghavan, K., & Yun, Y.S. (2008). Bacterial biosorbents and biosorption. *Biotechnology Advances*, 26, 266-291.

Wang, J. L., & Chen, C. (2009). Biosorbents for heavy metals removal and their future. *Biotechnol Adv*, 27(2):195-226.

.

.